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OPTIMAL LOAD SCHEDULING OF NIGERIAN POWER SYSTEM WITH VALVE POINT EFFECT USING JAYA OPTIMIZATION ALGORITHM

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ABSTRACT
Economic load dispatch is a non-linear optimization problem which is of great importance in power systems. This paper proposes the optimal scheduling of the Nigeria Integrated Power System considering valve point loading effect using Jaya Optimization Algorithm (JOA).Data was collected from national control centre Osogbo and was used to develop cost function for the thermal stations actively contributing power to the national grid. M file was written in MatLab R2012a environment using Jaya Optimization Algorithm, Pattern Search Algorithm (PSA) and Genetic Algorithm (GA) to optimally schedule power generation by the power system. Result obtained showed that scheduling with JOA produced a cost of 210.8092N/hr, PSA produced a cost of 211.9579N/hr and GA produced a cost of 212.6687N/hr. The simulation result shows the advantage of the proposed method for reducing the total cost of power generation by the system over the other methods.

Keywords: *load scheduling, value point, Jaya optimization, pattern search, genetic algorithm*

1. INTRODUCTION

Optimal Generation Scheduling (OGS) which can also be referred to as Economic Load Dispatch (ELD) in power system, is a constraint based optimization problem in power system that has the objective of dividing the total power demand among the online participating generators economically (optimally) while satisfying the essential constraints [1 – 4]. The conventional methods that have been used to solve this problem includes the Unconstrained Optimization methods, Linear Programming and Dynamic Programming, Newton's method and Interior Point method [5].
Other Artificial Intelligence (AI) based methods have been proposed for solving Optimal Generation Scheduling (OGS) problem such as Genetic Algorithm (GA) [6, 7], Tabu Search Algorithm (TSA) [8], Particle Swarm Optimization (PSO) [9, 10] Artificial Neural Network (ANN) [11], Evolutionary Programming (EP) [12] and Artificial Bee Colony (ABC) [5].
Electricity supply in Nigeria is epileptic, total power generated cannot meet the demand of the ever growing consumers. Investors have constantly moved to other countries because of the epileptic nature of power supply in Nigeria which has led to loss of job and the economy not developing at the rate it is supposed to [10, 13]. The power generating stations in the country are located at different point which are far from each other, some of the power stations are very old while some are new, which means they cannot have the same cost functions [14]. Also ageing infrastructure, weak and radial network instead of ring main configuration, and overloaded transformers leads to frequent system collapse, with high transmission and distribution losses and poor voltage profile [13]. Considering the above mentioned problems, it becomes necessary for us to study the cost functions of the integrated thermal generating stations, their power limits and the maximum power demand of the whole country so as to schedule generation effectively.
This paper proposes JOA as an optimization technique to optimally schedule the thermal power generating stations in the country and solve constraints based quadratic cost function with generator constraints. Results obtained are compared with GA and SA

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methods. The proposed methodology emerges as robust optimization techniques for solving the OGS problem for the Nigerian power system.

2. PROBLEM FORMULATION

The classic optimal generation scheduling problem minimizes the following incremental fuel cost function associated to the individual thermal power generating stations [15];

$$C_T = \sum_{i=1}^{N} C_i(P_i) \quad (1)$$

The cost characteristic are shown as

$$C_i = \alpha_i P_i^2 + \beta_i P_i + \gamma_i \$/hr \quad (2)$$

Where α_i, β_i and γ_i are constants.

2.1 Equality Constraints:

The real power balance in the system is given by

$$\sum_{i=1}^{N} P_{Gi} = P_d + P_{loss} \quad (3)$$

Where P_{loss} calculated using the B-Matrix loss coefficients and expressed in the quadratic form as given below:

$$P_{loss} = \sum_{i=1}^{n}\sum_{j=1}^{n} P_i B_{ij} P_j \quad (4)$$

Where B_{ij} is loss coefficient.

2.2 Inequality Constraints:

The generation power 'P' cannot be outside the range stated by the inequality

$$P_{i\min} \le P \le P_{i\max} \quad (5)$$

Where C_T total production cost (Rs/h); $C_i(P_i)$, is incremental fuel cost function (Rs/h); P_i, is real power output of the i^{th} unit (MW); N is number of generating units; P_d is power demand (MW); P_{loss} is power loss (MW); B_{ij} is transmission loss coefficients; P_{imin} is minimum limit of the real power of the i^{th} unit (MW); P_{imax} is maximum limit of the real power of the i^{th} unit (MW) [15 – 18].

The problem of optimal generation scheduling of real power is to be done to the required load demand by satisfying the above constrains.

2.3 Valve-Point Loading Effect

For more rational and precise modelling of fuel cost function, the above expression of cost function is to be modified suitably. The generating units with multi-valve steam turbines exhibit a greater variation in the fuel-cost functions [18]. The valve opening process of multi-valve steam turbines produces a ripple-like effect in the heat rate curve of the generators. These "valve-point effects" are illustrated in Figure-1 [19 – 21].

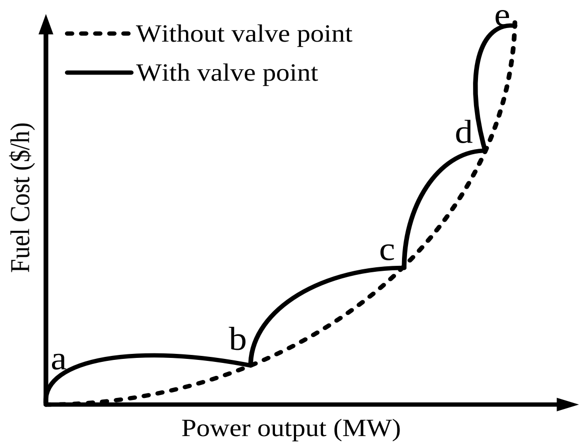

Figure 1: Valve Point loading effect

The significance of this effect is that the actual cost curve function of a large steam plant is not continuous bur more important it is non-linear. In reality, the generating units with multi-valve steam turbine have very different input-output curve compared with the smooth cost function. Therefore, the representation of the incremental fuel cost function of the generating units more practical. The incremental fuel cost function of a generating unit with valve-point loadings is represented as Equation (6).

$$C_i = \alpha_i P_i^2 + \beta_i P_i + \gamma_i + \left| e_i \times sin f_i \times (P^{min} - P_i) \right| \$/hr \quad (6)$$

Where e_i and f_i are the coefficients of generator reflecting the valve-point effects [19 – 21].

3. JAYA OPTIMIZATION ALGORITHM

Jaya optimization algorithm is a simple but powerful optimization algorithm developed by Dr. R. Venkata Rao in 2015 for solving the constrained and unconstrained optimization problems [22]. This algorithm is based on the concept that the solution obtained for a given problem should produce the best solution and should not produce the worst optimal solution. This algorithm requires only the common control parameters and does not require any algorithm-specific control parameters.

Let f(x) is the objective function to be minimized (or maximized). At any iteration I, assume that there are 'm' number of design variables (i.e. j = 1, 2…m), 'n' number of candidate solutions (i.e. population size, k = 1, 2,…,n). Let the best candidate obtains the best value of f(x) (i.e. f(x) best) in the entire candidate solutions and the worst candidate worst obtains the worst value of f(x) (i.e. f(x) worst) in the entire candidate solutions. If Xj,ki is the value of the jth variable for the kth candidate during the ith iteration then this value is modified as per the following Equation [23].

$$X'_{j,k,i} = X_{j,k,i} + r_{j,k,i}\left(X_{j,best,i} - \left|X_{j,k,i}\right|\right) - r_{2,j,i}\left(X_{j,worst,i} - \left|X_{j,k,i}\right|\right) \qquad (7)$$

$X_{j,best,i}$ – the value of the variable j for the best candidate

$X_{j,worst,i}$ – is the value of the variable j for the worst candidate,

$X_{1j,k,r}$ is the updated value of $X_{j,k,i}$

$r_{1,j,i}$and $r_{2,j,i}$ – are the two random numbers for the j[th] variable during the i[th] iteration in the range [0, 1].

$r_{1,j,i}$ ($X_{j,best,i}$ –|$X_{j,k,i}$|) – indicates the tendency of the solution to move closer to the best solution.

$r_{1,j,i}$ ($X_{j,worst,i}$ –|$X_{j,k,i}$) – indicates the tendency of the solution to avoid the worst solution. $X_{1j,k,i}$ is accepted if it gives better function value.

All the accepted function values at the end of iteration are maintained and these values become the input to the next iteration. The algorithm always tries to get closer to success (i.e. reaching the best solution). The algorithm strives to become victorious by reaching the best solution and hence it is named as Jaya [17, 22, 23].

4. RESULT AND DISCUSSION

The cost function of the Nigerian Integrated thermal generating stations were used in the total fuel cost. The cost functions of the thermal stations, their maximum and minimum power limits with valve point effects based on data obtained from the National control centre Osogbo are given in Table 1 [16]. The load demand to be satisfied was 3500 MW (without considering transmission losses). To find the optimal scheduling for the Nigerian power system, the following techniques have been utilized: Jaya Optimization Algorithm, Genetic Algorithm (GA) and Pattern Search Algorithm (PSA). The population size, maximum and minimum generation limits and iteration count for the power system was fixed. The results for the power system applying JOA, GA and PSA are shown in Table 2. The programs were written and ran in MATLAB environment. According to the constraints considered in this work among inequality constraints only active power constraints are considered. There operating limit of maximum and minimum power are also different. The unit operating ranges given in the Table 1 [16] i.e. $P_i^{\min} \le P_i \le P^{\max}$.

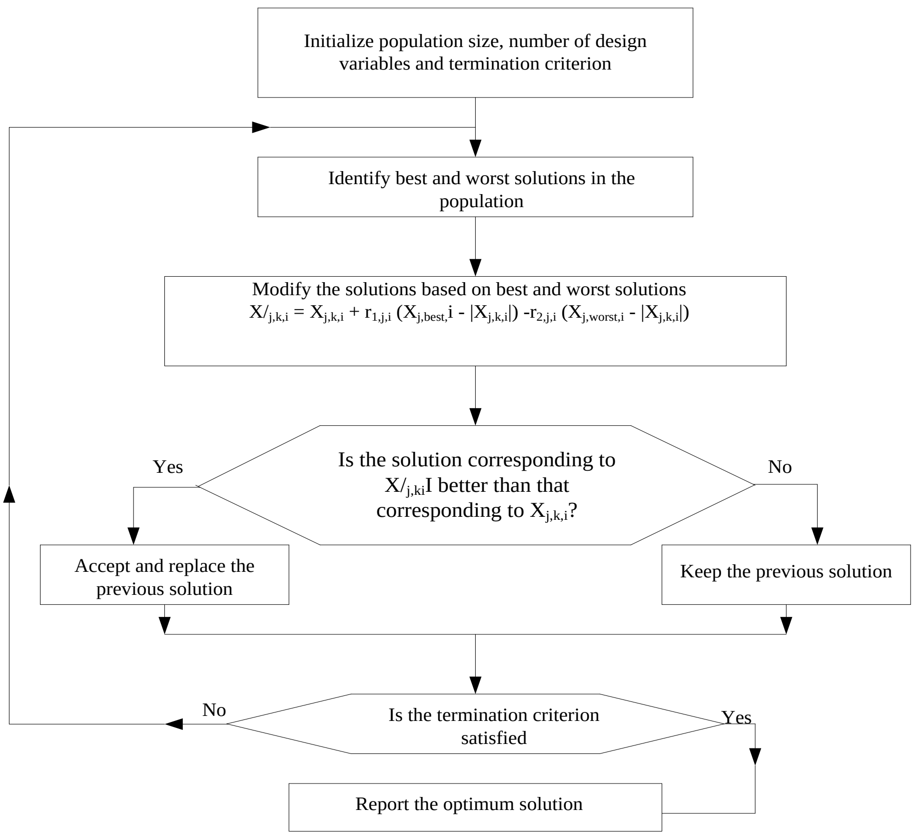

Figure 2: Flow Chart of Jaya Optimization Algorithm

Table 1: Data for Nigerian Integrated thermal power stations.

S/N	Power Stations	a_i	b_i	c_i	e_i	f_i	P_i^{min}	P_i^{max}
1	EGBIN ST(GAS)	0.0000109	0.0284	3.92	310	0.0086	118	1100
2	SAPELE ST	0.0000591	0.0226	8.10	200	0.0042	33	223
3	DELTA II-III	0.0000757	0.0326	6.47	80	0.0098	10	110
4	DELTA IV	0.0000743	0.0334	9.85	230	0.0047	22	434
5	GEREGU	0.0000201	0.0313	1.25	270	0.0037	14	450
6	OMOTOSHO	0.0000514	0.0312	4.70	280	0.0039	29	480
7	OLORUNSOGO	0.0000294	0.0313	2.80	210	0.0043	10	293
8	AFAM IV-V	0.0000834	0.0289	2.03	271	0.0048	24	453
9	SAPELE GT NIPP	0.0000105	0.0227	5.60	211	0.0044	30	373
10	ALAOJI NIPP	0.0000200	0.0332	3.00	120	0.0077	34	87
11	GEREGU NIPP	0.0000223	0.0314	1.00	190	0.0039	94	272
12	OLORUNSOGO NIPP	0.0000287	0.0313	1.70	225	0.0046	31	422
13	OMOTOSHO NIPP	0.0000179	0.0313	2.64	185	0.0045	20	225
14	IHOVBE NIPP	0.0000200	0.0294	1.00	80	0.0098	91	120
15	OKPAI	0.0000326	0.0286	4.53	292	0.0034	100	475
16	AFAM VI	0.0000115	0.0286	8.00	320	0.0036	45	656
17	AES	0.0000133	0.0286	4.30	215	0.0043	51	242
18	OMOKU	0.0000442	0.0314	1.30	112	0.0076	3	65
19	IBOM	0.0000189	0.0312	4.60	80	0.0098	10	101
20	TRANS AMADI	0.0000315	0.0311	1.00	67	0.0083	4	31
21	RIVERS IPP	0.0000215	0.0318	6.00	120	0.0077	20	160

Table 2: ELD with valve point effect neglecting loss

S/N	Power Stations	Method of Optimization		
		JOA	PSA	GA
1.	EGBIN ST (GAS)	278.8012	352.4037	605.3239
2.	SAPELE ST	39.6827	40.4529	185.8841
3.	DELTA II-III	52.3329	103.8878	98.9096
4.	DELTA IV	77.7609	307.3493	84.1693
5.	GEREGU	281.0872	28.3088	360.2352
6.	OMOTOSHO	379.0098	76.353	181.1366
7.	OLORUNSOGO	81.8758	272.045	232.2028
8.	AFAM IV-V	183.7561	240.1686	156.3046
9.	SAPELE GT NIPP	228.7876	346.7002	140.6664
10.	ALAOJI NIPP	45.6829	84.2063	44.4524
11	GEREGU NIPP	186.1249	169.4776	136.9487
12	OLORUNSOGO NIPP	312.9043	264.9911	418.4326
13	OMOTOSHO NIPP	38.6737	171.7743	194.2104
14	IHOVBE NIPP	120	91.7641	93.2798
15	OKPAI	297.6855	122.4395	113.4729
16	AFAM VI	531.7802	419.4505	74.8461
17	AES	168.813	240.9073	171.6475
18	OMOKU	22.1318	11.4436	8.7339
19	IBOM	39.2315	64.326	53.3774
20	TRANS AMADI	26.9677	16.91	8.6454
21	RIVERS IPP	106.9102	74.6404	137.1203
TOTAL COST(N/hr)		210.8092	211.9579	212.6687
ITERATION		90	220	310

To investigate the effectiveness of the proposed JOA, Genetic Algorithm (GA) and Pattern Search Algorithm have been considered for the purpose of comparison. The outputs using all the three algorithms have been shown in Table 2. It is seen that the results obtained from JOA are almost same with the results of the other two methods, but the JOA have shown superiority over the other two methods. The minimum cost obtained by JOA is 210.8092N/hr and converged after 90 iterations, the minimum cost for PSA is 211.9579N/hr and converged after 220 iterations and the minimum cost for GA is 212.6687$/hr and converged after 310 iterations. The results demonstrate that the proposed algorithm outperforms the other methods in terms of optimal solutions. In table 2 the optimal value of power generation with the effect of valve point is achieved using JOA within the operating limit as given in Table 1. Hence, with the help of these optimized value of power generations which meets 3500 MW demand we able to obtain the optimum minimum cost of total generation. The convergence profile of the cost function is depicted in Fig 3, optimal generation scheduling of the Nigerian Integrated Power System shown in the Fig 4.

5. CONCLUSION

The optimum cost for the Nigerian Integrated Power System with valve point effect is achieved by JOA and after comparing with GA and PSA it is found that the proposed algorithm outperforms the other methods in terms of better optimal solution and the best ELD solutions obtained by the proposed method for the load demand of 3500 MW. The performance of JOA proved to be effective while satisfying the constraints with highly probable solutions in an acceptable computing time. Jaya Optimization Algorithm has therefore proved to be the very effective technique to solve Economic Load Dispatch problem with valve-point consideration.

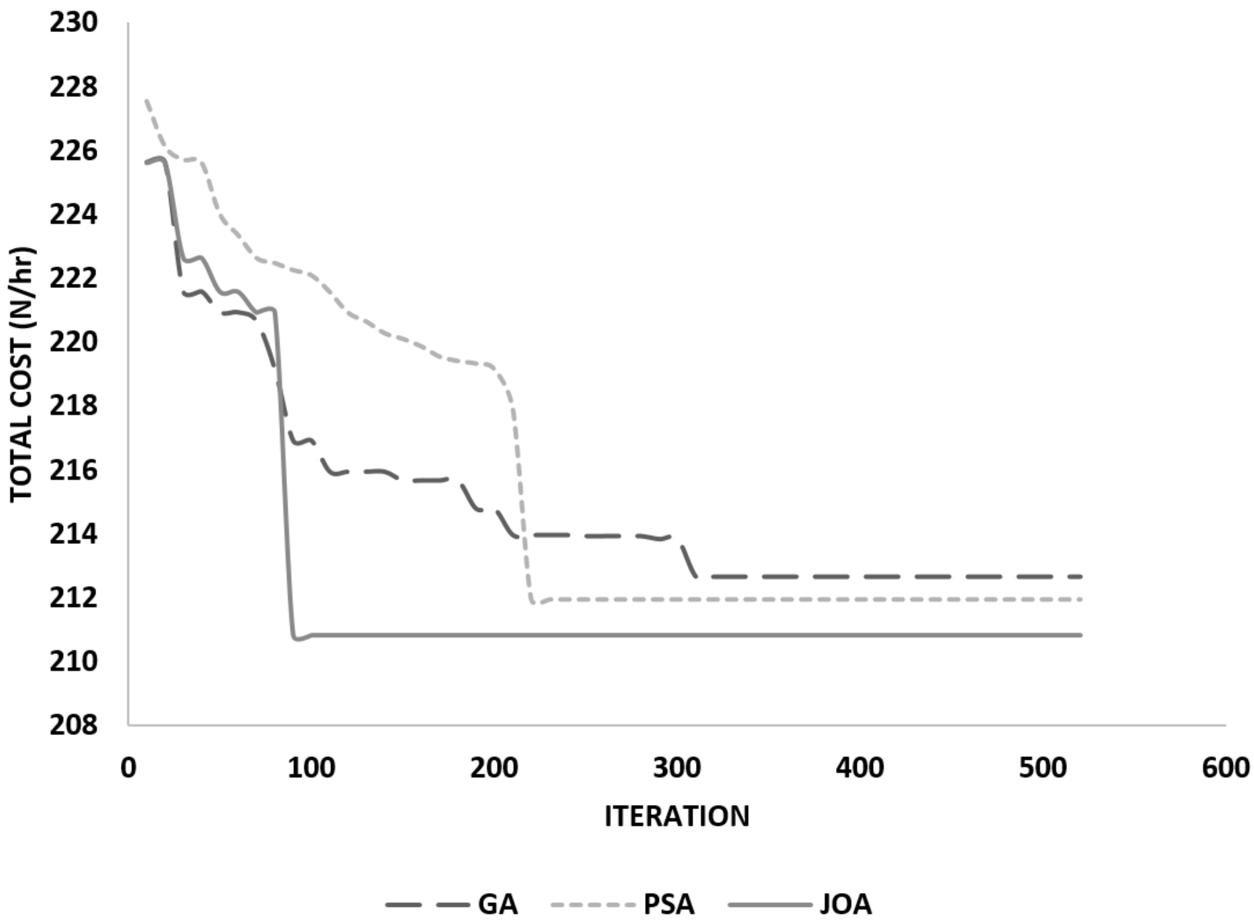

Figure 3: Cost curve of 3500 MW demand by JOA method with valve point effect without loss

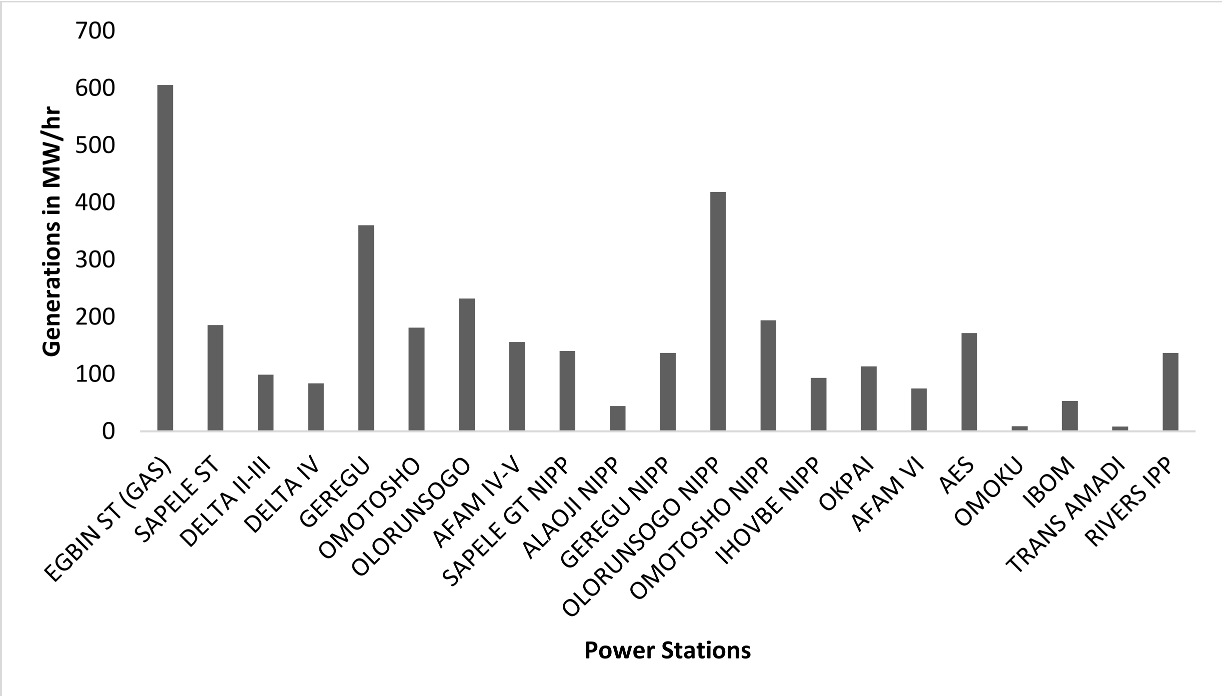

Figure 4: Optimal Generation Scheduling of 3500 MW demand by JOA method with valve point effect without loss

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